Contextual Geotracking Service of Incident Markers in Disaster Search-and-Rescue Operations

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Abstract—Real-time geovisualization of disaster scenes provides visual situational awareness, which could decrease medical triage time, and also allows first responders to better allocate relief resources. In this paper, we describe a novel contextual geotracking service that provides spatiotemporal visualization of response history through the use of mobile devices and a wireless mesh network. During crisis response, with limited resources in a high-stress disaster relief environment, contextual data visualization of disaster incident scene status markers, and their presentation in a usable dashboard is crucial. We present novel visualization tools that we have developed to integrate custom map markers, tracking information collected through a wireless network, geovisualization over time through gradients, and spatiotemporal event filters. We evaluate our geotracking service in a field trial with a search-and-rescue task force comprising of professional first responders. We show effectiveness of our service in terms of data entry time, usability survey, and qualitative feedback within a disaster response simulation experiment.

I. INTRODUCTION

Lack of usable technology due to the destruction of infrastructure during natural disasters can prevent first responders from responding as quickly and efficiently as possible. Lack of infrastructure significantly limits what types of technology can be implemented and standardized for national emergency response teams. Currently, responders are sent into the field with hand-held devices to record data for future analysis. This lack of real-time information contributes to an incoherent overview of the scene for incident commanders (ICs), which consequently leads to difficulties in filtering accurate and updated information, allocating resources, and prioritizing e.g., patient triage in medical relief efforts.

In our previous work, we have developed the Panacea’s Cloud [1] that aims to serve as a real-time communication and coordination tool designed to provide situational awareness to incident commanders and responders in disaster scenarios. Panacea’s Cloud uses an ad hoc network that is independent of existing infrastructure, such as an 802.11 wireless network or radio towers, which may be disrupted during a disaster. It enables first responders such as, firefighters and emergency paramedics, to work together to most effectively survey a scenario and provide treatment. Decreased triage time ultimately allows for efficient allocation of resources and could save lives.

In this paper, we extend our Panacea’s Cloud by developing a novel contextual geotracking service of incident markers in disaster search-and-rescue Operations. To this end, we work collaboratively with Missouri Task Force 1 (MO-TF1), an organization of first-responders, based in 28 locations around the United States, who specialize in search-and-rescue and medical triage. Technological limitations are often encountered by MO-TF1 after natural disasters, such as Hurricane Katrina, and correspond closely to the problem Panacea’s Cloud seeks to resolve.

Currently, MO-TF1’s state-of-the-art technology is limited to hand-held GPS devices with a custom symbol set. These GPS devices do not allow for real-time data routing and are dependent on a central computer for synchronization. Immediately upon return from a search, responders must both upload and download data through a USB connection. A new search team is immediately dispatched after the return of another, which does not allow enough time for data analysis and integration. Therefore, no new information can be distributed until the second dispatch team returns and the third is dispatched. After synchronization, which is dependent on the number of responders, the data is analyzed through custom macros in Microsoft Excel to gain situational awareness [2].

In the absence of GPS devices, traditional handset radios and paper triage tags are used. However, communication can be disrupted (e.g., background noise during a disaster situation that interferes with radio units), and consequently, handset radios can be unreliable in quickly and accurately conveying and receiving information. Similarly, paper triage tags do not allow for real-time location tracking and information updating (e.g., the movement of patients over time or the number of patients classified per triage level). Existing works such as DIORAMA [3], under development by the University of Massachusetts Amherst, aim to solve the problem of medical triage during mass casualty incidents through active RFID readers and tags that transmit information, and support tools for IC communication and patient tracking user interfaces. However, they rely on infrastructures of cell and radio towers, and do not leverage ad hoc wireless networking at disaster incident scenes.

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To address the above challenges, we enhance the real-time component of Panacea’s Cloud for the processing and display of spatiotemporal information that is essential for ICs to gain an accurate depiction of the past and present events to best allocate resources and effectively respond. Due to the dynamic movement of responders in the field, our solution helps an IC to visually analyze coverage and organize relevant information through filters. Furthermore, to decrease cognitive burden associated with visual analysis, we develop novel spatiotemporal information visualization on the dashboard in an intuitive manner and in a way that requires minimal temporal processing and interaction with the interface.

The remainder of the paper is organized as follows: Section II outlines our geotracking and visualization objectives and novel visualization tools that we have developed. Section III presents experimental methods and results with MO-TF1. Section IV concludes the paper.

II. CONTEXTUAL GEOTRACKING AND VISUALIZATION

A. DESIGN OBJECTIVES

In the case of crisis response in a limited-resource and high-stress healthcare environment, data visualization and dashboard usability are crucial. Given the dynamic nature and high-stakes involved in mass causality incidents, the IC must be able to quickly interpret the available data of a scenario at any given moment and then use the dashboard effectively to allocate appropriate resources. Prior experience with similar systems can mitigate a user’s error rates [4]. However, the assumption cannot be made that such experience exists. Assuming the user has no prior experience, it is essential for a dashboard to minimize cognitive burden and facilitate information processing. In this paper, we seek to address methods and tools in which Panacea’s Cloud’s user interface gives a spatiotemporal visualization of the patient story with limited visual-cognitive demand.

B. VISUALIZATION TOOLS

The following interface tools were implemented using JSX, which adds XML-syntax to Javascript; React, a Javascript library that renders UI components based on data change; and Redux, a state container changed through dispatched actions. These tools were chosen specifically for their efficient comparisons and re-rendering of current and incoming data. Visual component libraries that we used include: Leaflet, Leaflet plugins, Bootstrap, and React-adapted Bootstrap UI components.

1) Custom Markers: A common method of spatial indication on maps is the use of markers. However, for a disaster response interface, generic markers are severely limited in their ability to convey information as seen in Figure 2. Generic markers lack distinguishable features which contributes to users’ inability to differentiate between markers. In addition, generic markers typically do not display meta-information that is vital in determining further action. Finally, generic markers are not interactive and do not provide an option for actionable updates such as updating the status of a marker. Due to these limitations, generic markers are not suitable for Panacea Cloud’s dashboard.

Custom markers are added to the dashboard using a combination of Javascript libraries as shown in Figure 2. The different markers include features, such as icons and colors, which allows users to differentiate between them. To suit any user’s particular needs, the marker icon, color, and description are customizable through a centralized JSON configuration file. The freedom to edit, add, or remove the custom markers confers an element of extensibility to Panacea Cloud’s dashboard, eases transition from previous systems, and lessens the cognitive demand in interpreting data. To expand on the visual information provided by the markers, a pop-up of plain text and/or pictures is available through user interaction to allow for visual geotagging of static points (e.g., a road block) and dynamic points (e.g., a resource in motion).

In our MO-TF1 use case, twenty-four custom markers, currently used on the MO-TF1 GPS systems, are configured into a JSON file. When clicked, the name and description of the custom symbol is displayed as shown in Figure 2. To differentiate MO-TF1 responders from incident markers, a different icon is used. The responder markers can also display information in pop-ups.

2) Tracking Information: A significant deficit of markers is the lack of time integration. Markers handle the indication of spatial location well, but can only display current location without reference to past locations. In the case of disaster response, the loss of past information is highly critical. Thus, creating tracks between markers to visualize past locations is a means of adding a temporal component to maps.
As shown in Figure 3, paths visualize a survey history in an area and differentiate incoming data, including but not limited to responder-to-search-area ratios, responder search efficiency, specific device failure, total areas searched and needing to be searched. Incident markers can be directly linked to a responder, allowing for tests of accuracy (e.g., a marker an IC may expect to see during training and the actual marker entered). A progression of the scene can then be traced as an expanding coverage of an area of disaster. The logging of the data allows for future analysis of composite search-and-rescue data as well as future analysis of specific responder data. The former can lead to improved search-and-rescue methods that minimizes loss of lives, and the latter can lead to improved training methods.

We used a model to relate the rendered components to each responder or custom marker, which in turn refers to a geotag’s type ID for filtering. Each responder, hardware device, and custom marker has a unique ID. This differentiates between responder and device and creates flexibility for a case where a responder may have to use a different device, due to issues such as hardware. This also allows for easy testing of devices, as device failure while tracking can be viewed on the dashboard in real-time. Within the custom marker, the responder unique ID is also recorded, which connects the responder to their markers. On the dashboard itself, each responder has their own path, marker, and pop-up, while each marker has its own marker and pop-up.

3) Geovisualization Over Time Through Gradients: The use of paths behind markers, to indicate past locations of responders and incidents, is a geovisualization over a temporal frame. However, in the implementation of these paths, specificity of information is lost, and relative times cannot be determined. For example, a marker indicates a responder’s current location at a specific time, while a path indicates a responder’s past location at a nonspecific time.

One proposed solution is a dynamic timeline playback. However, due to its nature, this has a high temporal cost, forcing a user to view a dynamic image over a period of time in order to determine the location of markers at a specific time within the timeline. In the case of disaster response, this is precious time that could be better allocated. To create a static image that both displays specific spatial and temporal information, gradient paths are implemented. Figure 4 displays the mapping of a gradient path to a timeline key with timestamp labels. This allows a user to process a single static image and extract spatial and temporal information about a scenario without continuous playback. Thus, a user can use the color of a gradient to determine the spatial record of resources and responders at a specific time or within a time frame.

The use of gradients to map information confers all the advantages that a solid-colored line does, including information related to specific responders and progression of coverage. In this case, gradients provide a clearer view of temporal progression as well as an overall view. Regarding real-time data upload and display, as in the Panacea’s Cloud dashboard, the use of gradients visually organizes incoming information.

One criticism of gradients is the reliance on color and a lack of accessibility to colorblind users. To address this issue, a colorblind palette shown in Figure 5 is used to address the two common forms of colorblindness: protanomaly and deuteranomaly. Colorblindness is estimated to effect 8% of men and 0.5% of women worldwide. Of total colorblind population, 75% of colorblind men have either protanomaly or deuteranomaly [5]. Consequently, a palette adjusted for red-green colorblind users increases accessibility. The option to configure with specific hex triplets is also available through a JSON file. Like with the custom markers, the centralized characteristic of configuration files allows this dashboard to extend to multiple use cases beyond search-and-rescue.

The implementation of gradients for the Panacea’s Cloud dashboard was received positively by MO-TF1, especially given that gradients are not a feature available on their current system. The usability, accessibility, and immediate applicability of the gradients to search-and-rescue operations makes it a vital component to the Panacea Cloud’s dashboard for extracting spatial and temporal information without time resource allocation.
4) Spatiotemporal and Event Filter: In the case of vast amounts of incoming data or an incident with multiple events (e.g., an earthquake with multiple aftershocks), analysis of an event rather than the incident may be preferable. Accomplishing this necessitates the ability to select a time frame in which data can be analyzed. By changing the display view, a spatiotemporal filter decreases the visual-cognitive burden of the IC by removing distracting or currently irrelevant information and allows for more accurate analysis.

To focus on an event in an incident, a spatiotemporal filter is available on the Panacea’s Cloud dashboard. A user is able to select the timespan for the desired view. By default, if the whole view is selected or a view including the most recent timestamp is selected, incoming data is always included. This removes the task of re-adjusting the slider constantly. Dragging the display slider through the filtered times changes the view dynamically. An example is shown in Figure 6. A play/pause button is also available for users who prefer to play back an event at a consistent rate, starting at either a specific time within the filter or at the start of the filter; the button allows for user interruption on the detection of change events within the slider. The filter determines the gradient paths displayed, while the marker above the filter indicates how far along the filtered path that the resource has traveled. The display therefore shows past, present, and future progression, and allows for greater precision in the playback of scenes.

III. PERFORMANCE EVALUATION

A. EXPERIMENTAL METHODOLOGY

To compare MO-TF1’s current Garmin GPSMAP 64 system to Panacea’s Cloud, we ran three trials: Trial One tested Panacea’s Cloud with Recon Jets, Trial Two tested MO-TF1’s current hand-held Garmin system, and Trial Three tested Panacea’s Cloud with a Mobile View on Android devices.

Standard training procedure for MO-TF1 involves the placement of laminated placards symbolizing “incidents” with characteristics corresponding to the custom MO-TF1 markers (e.g., number of victims, detection of human remains, destroyed structure, etc.) onto wooden stakes along a road to simulate a neighborhood for search-and-rescue. The placards are traversed by responders, and the characteristics are entered as quickly and accurately as possible.

Trial One was performed a week before Trials Two and Three and without MO-TF1 participants present. The preliminary results of the trial determined that Recon Jets, do not provide suitable hardware for the MO-TF1’s use case, which most likely can be contributed to the lack of a competitive wearable technology market at this time. Transmission of data though the Recon Jets relied on an internal camera, to photograph QR codes corresponding to the custom markers, which produced overexposed images in both high and low contrast environments. The internal GPS displayed high rates of GPS scatter and inaccuracies which greatly impacted the coherence of an incident. The user interface was unusable for data entry and data verification due to the application closing at inappropriate times and its inability to confirm the data was received by the incident commander.

Thus, to suitably and more rigorously test Panacea’s Cloud, a mobile application was created for data entry; Figure 7 displays the screen as seen by users. The application was accessed locally on Android devices, given to MO-TF1 participants in Trial Two, with instructions on application use. Our focus in this paper will be on the results of Trials Two and Three.

For further data organization, a reset button is placed on the dashboard to separate incidents. Upon user interaction, the reset button makes a call to the API for a new incident, which clears the current data from the dashboard without changing its storage within the database. This enables the IC to access and display cleared data later as a separate incident. To keep users from accidentally double-clicking and sending two incident requests, the button is disabled during fetching.

The separation of data into multiple incidents and events within an incident filters the data in a user-controlled way. This creates dashboard-displayed information that is more usable; gradient paths and markers become more effective through filtering. Additionally, incident creation and incident-event filtering makes Panacea’s Cloud’s dashboard extensible and applicable to other use cases, such as device tracking or more efficient ambulatory aid.
but filtered out. For the Garmin system, a separate time was recorded for the upload of data from the handheld devices through the USB. For Panacea’s Cloud, the time between the last marker recorded and its appearance on the dashboard was taken as a rough indicator of update time.

To determine MO-TF1’s subjective perception of the current Garmin system and Panacea’s Cloud’s Mobile View for data entry, the participants completed a usability survey containing 10 questions, rated on a Likert scale of 1 to 5.

- I think that I would like to use this system frequently.
- I found this system unnecessarily complex.
- I thought the system was easy to use.
- I think that I would need the support of a technical person to be able to use this system.
- I found the functions in this system well integrated.
- I thought there was inconsistency in this system.
- I would imagine that most people would learn to use this system quickly.
- I found this system very cumbersome to use.
- I felt very confident using this system.
- I need to learn a lot of things before I could get going with this system.

Additionally, the same usability survey was completed by the acting IC for both Iron Sights, the current Garmin dashboard [2], and Panacea’s Cloud dashboard. A qualitative analysis was also conducted to gather feedback regarding suggested improvements to Panacea’s Cloud dashboard.

B. EXPERIMENTAL RESULTS

As shown in Figure 8, the average data entry time per incident for Panacea’s Cloud was 3.6x faster than the data entry time per incident for the Garmin system. For the current Garmin system, the total time taken by the participants in entering data for the 29 incidents was 850 seconds (≈14.2 minutes) and 1193 seconds (≈19.9 minutes). This averages to 35.2 seconds per incident. For Panacea’s Cloud, the total time taken for the same 29 incidents was 329 seconds (≈5.5 minutes) and 242 seconds (≈4.0 minutes). This averages to 9.8 seconds per incident.

One notable difference is the Garmin system’s higher score in confidence of use. This outcome was not surprising because the Garmin is the system they are comfortable and currently using.

Qualitative analysis of the data reveals that gradients were received positively by the IC. Suggestions for the dashboard included an ability to enter a bulk number of markers, a tally for each marker, data verification for the user that a marker is successfully sent, and dates of incidents under a separate tab on the dashboard.

IV. CONCLUSION AND FUTURE WORK

Our experimental trials display a 3.6x decrease in data entry time using the Panacea’s Cloud contextual geotracking service instead of the handheld Garmin system. This decrease of time in sending and retrieving data is indicative of a reduction in time of search-and-rescue missions as well decreased triage time. We found that the Garmin system upload time is dependent on the number of users, while Panacea’s Cloud acts in real-time data display on the dashboard. This creates a scalability for Panacea’s Cloud that does not apply to the current Garmin system used in search-and-rescue efforts of groups such as MO-TF1. The usability survey results and positive feedback also indicate greater system usability. Further trials with a larger sample size and greater control of variables are needed for more conclusive results.

Outside of search-and-rescue operations, the Panacea’s Cloud dashboard is extensible to other use cases where geovisual information must be displayed and filtered over a timespan, such as medical triage, device tracking, or environment monitoring. Because of these many use cases, future work on Panacea’s Cloud dashboard is focused on increasing usability and adding to the available features.

REFERENCES


Fig. 8. Total time taken by each user to enter 29 incidents for each tested

Fig. 9. Usability questionnaire results indicate Panacea’s Cloud outperforms the current Garmin GPS system in 9 out of the 10 categories